Review

Obtaining a Sustainable Competitive Advantage from Patent Information: A Patent Analysis of the Graphene Industry

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Abstract: Graphene serves as the most disruptive material in the twenty-first century and plays an unsubstitutable role in solving the sustainable development problems of energy crises, water shortages, and environmental pollution. Recently, obtaining a sustainable competitive advantage (SCA) in the field of graphene has gained increasing attention from both researchers and practitioners. However, few attempts have been made to summarize the SCA of this field by applying patent information. Basing on a patent-based multi-level perspective (MLP), this study aims to develop an approach to identify SCA in the target technological area by conducting a patent review from the comprehensive perspectives of the macro landscape, meso socio-technical system, and micro niches, and then integrate patent analysis with technology life cycle (TLC) theory to examine patents involving global technological competition. The effectiveness of the approach is verified with a case study on graphene. The results show that the graphene field is an emerging and fast-growing technological field, with an increasing number of patents over the year. The TLC of graphene technology demonstrated an approximate S shape, with China, the U.S., Korea, and Japan filing the largest number of graphene patents. Evidenced by Derwent Manual Codes, we found an increase in consideration given to technological application and material preparation topics over time, and research hotspots and fronts that have SCA. In terms of a leading country or region with SCA, the U.S., with a high foreign patent filing rate, large number of high forward citation patents, strong assignees' competitive position, and large number of high-strength patents, was still the most powerful leader, with a higher SCA in the graphene industry. Korea also obtained a relatively higher SCA and will be a promising competitor in this field. Although China was shown to be catching-up very rapidly in the total number of graphene patents, the apparent innovation gaps in the foreign patent filing rate, high value patents, and Industry-University-Research Collaboration will obviously hamper Chinese catch-up efforts for obtaining SCA. As for patentees, the most powerful leaders with a higher SCA represented by Samsung Electronics Co., Ltd, International Business Machines Corp, and Nanotek Instruments Inc were identified. In addition, most of the high strength patents were owned by the above patentees. Further, valuable contributions to the understanding of SCA in graphene technology were summarized. First, the proposed patent-based MLP provides a new and comprehensive analytical framework for review research, as well as SCA analysis, and extends its research perspectives. Second, it introduces patent indicators to the previous MLP model, and provides a new theoretical perspective for the study of technological innovation in the previous MLP model. Third, this paper employs the TLC theory to explore the dynamic SCA in the given technology field, which further develops the concept of the MLP model from the temporal dimension. Finally, future research directions were demonstrated. To the best of the authors'

knowledge, this is the first systematic review of this field using patent analysis, comprehensively acknowledging the current technological competition and development in the graphene field and that of the future, and can be applied to various other emerging technology fields.

1. Introduction

With the intensification of global technological competition and the shortening of the technological innovation cycle, there has been great interest in how technological innovation subjects (e.g., enterprises, universities, and research institutes) will obtain a sustainability competitive advantage (SCA). In the last decade, academicians and practitioners have attached great importance to the question of what constitutes SCA. Numerous arguments have been proposed as to the source of SCA. Prahalad and Hamel [1] argued that core competencies are the roots of firms' SCA, and defined core competencies as "the collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple stream of technologies". Some researchers [2,3] indicated that an asset's inimitability is the basis for firms' SCA. Leonard-Barton [4] maintained that if the knowledge a company accumulates throughout its development process is difficult for its competitors to replicate, this knowledge is important to its SCA. Akram et al. [5] indicated that information technology capabilities (ITC) based on a resource-based view and knowledge management capabilities (KMC) based on a knowledge-based view are two principal sources of a more-enduring competitive advantage in the information technology research field.

However, as the pace of technological innovation has accelerated, patent information has been touted as being the type of resource which provides a basis for SCA in the knowledge economy era [6]. A patent is regarded as a temporary monopoly on a particular use of knowledge, because it is combined in firms' useful inventions [7]. It is interesting to find that patent information contains enormous and rich technical items, and 80% of technology information can be found in patent information [8]. Bloom and Van Reenen [9] indicated that patents help to exploit knowledge, improve a firm's productivity, and increase product differentiation. They are a basis for a longer-lived competitive advantage. Patent information is one of the most important indicators based on both a resource-based view and knowledge-based view, which successfully identify technology opportunity and obtain SCA for both public and private sector entities in their marketplace.

Graphene, a two-dimensional atomic crystal made up of carbon atoms arranged in a honeycomb lattice, was discovered by Prof. Andre Geim and Prof. Kostya Novoselov in 2004 and is regarded as one of the "miracle materials of the 21st Century" [10]. It possesses various amazing and extraordinary properties, such as the highest known electron conductivity, excellent thermal conductivity, huge specific surface area, high intrinsic strength and high Young's module, extremely high mobility, high elasticity, and electromechanical modulation [11]. Graphene is a complex technology and has great potential in a wide range of industries. To better understand the whole graphene industry, we classified graphene technology into upstream industry, mid-stream industry, and downstream industry (in Table 1) based on European graphene flagship [12]. In this study, upstream industry of graphene technology is mainly about raw material, material extraction, and preparation. Mid-stream industry focuses on the structure and properties of graphene. Additionally, we divided the downstream industry into the following five groups: new energy, electronics, composite materials, biomedical, and environmental protection. Considering its unique combination of superior properties, the innovative applications of graphene are fueling contributions in areas related to sustainable energy and environmental technologies, such as superadsorbents, ultrasensitive sensors, advanced

environmental and water splitting photocatalysts, chemical solar cells, fuel cells, supercapacitors, and rapid charging/discharging batteries [13].

Table 1. Industrial chain of graphene technology.

Industrial Chain	Technological Field
Upstream industry	Graphite; CVD graphene preparation method; Carbonaceous gas, e.g., methane
Mid-stream industry	Graphene film; Graphene powder; Graphene-based compound
Downstream industry	New energy industry: Lithium-ion battery; Supercapacitor; Solar cell Electronics industry: Flexible display device; Sensor Composite materials industry: Electrical conductivity composite material; Heat conductivity composite material; Reinforcement material Biomedical industry: Drug carrier; Gene therapy; Biological detection Environmental protection industry: Sea water desalination; Sewage disposal

Since the year following the 2010 Nobel Prize in Physics award for earlier pioneering work on graphene, there has been rapid growth in global graphene technological innovative management [14]. Substantial efforts and governmental funding from many countries or regions, such as the U.S., China, the U.K, the EU, Korea, and Japan, have been focused towards graphene research and development. For instance, the National Science Foundation of the United States (NSF) sponsored more than 500 graphene-related projects and the amount of subsidy exceeded 200 million dollars between the years of 2002 to 2013. The British government funded 540 million euros and 530 million euros to set up the National Graphene Institute and the Graphene Engineering Innovation Centre, respectively. The Korean Ministry of Knowledge Economy invested 250 million dollars in the graphene-related field from 2012 to 2018, including 124 million dollars for technical research and development and more for commercialization. The Japanese Ministry of Economy, Trade and Industry invested 59 million dollars in graphene-related technology from 2004 to 2011. Although the Chinese government has issued a series of written policies, such as "Made in China 2025", "13th Five-Year" National Science, and technology innovation planning, there is still a gap between China and countries or regions mentioned above in terms of financial funding. According to the IDTechEx Report [15], the global market in the promising area of graphene will be worth above 300 million USD by 2028. Yet, there is also the realization that the development and application of graphene technology is still in the early stages. More advanced designs and large-scale applications have yet to fully emerge out of laboratories and into the market [15]. While there has already been concern about the promising development of graphene technology, it would seem that obtaining SCA will necessarily require a comprehensive understanding of the global technological competition market.

However, although patent information has been widely recognized as the key to SCA, few studies have integrated macro-level, meso-level, and micro-level data, and even fewer have examined graphene patenting activities from the perspective of SCA. It is difficult to provide a comprehensive framework for technological innovation subjects on how to gain SNA through fierce global technological competition. This study contributes to this task of proposing a new and comprehensive patent-based SNA methodology based on a multi-level perspective (MLP), and aims to identify the SNA of technological innovation subjects in the graphene industry by collecting and analyzing ten thousand graphene patents from 2004 to 2017. Our findings could assist researchers and practitioners around the world in better understanding the current technological competition state of graphene-related patents, encouraging them to make the right decisions in patent strategy planning and obtain SCA, inspiring further research in the future. The remainder of this paper is organized as follows. Section 2 presents the literature review. In Section 3, methodology related to the patent-based MLP on SCA is presented. In addition, we explain the patent retrieval process. In Section 4, we carry out a case study in the field of graphene technology to illustrate the practical application of this novel approach. Section 5 concludes and discusses the main findings, contributions, future research directions, and limitations.

2. Literature Review

2.1. Patent Analysis for Graphene Technology

Patent analysis is a robust approach that has been widely used to identify technological competition, strategize the future patent layout in a target technological field, and assist technological innovative subjects to obtain SCA in the fierce market competition [16]. Patent statistics analysis and patent bibliometrics analysis are two widely-used patent analysis approaches. Patent statistics analysis, which can also be called patent descriptive analysis, collects mathematical data at first, and then counts data and makes data into tables or graphs [17]. However, patent bibliometrics analysis is a deep patent data mining and visualization presenting process [18]. Some databases, such as USPTO, Derwent Innovations Index (DII), and INNOGRAPHY, can be used for patent analysis. Several analysis tools have been employed in the field of patent analysis, such as citation analysis, co-word analysis, cluster analysis, and cooperation analysis [19]. Some proprietary visualization software has been produced for patent analysis, such as VOSviewer, Cite Space, and CiteNet Explorer [20].

Graphene, a new type of two-dimensional nano material with exceptional properties, was discovered by Prof. Andre Geim and Prof. Kostya Novoselov of the University of Manchester in 2004. It is regarded as the most disruptive emerging technology in the twenty-first Century. When graphene technology enters the growth phase, the global development of graphene has accelerated, and the number of patents has rapidly increased. Several researchers aim to analyze the social influence of journals to identify emerging research topics in the field of graphene. Lv et al. [21] employed bibliometric analyses to probe trends in graphene research and identified three key journals (Physics Review B, Applied Physics Letter, and Physical Review Letter) during 1991-2010. Etxebarria et al. [22] used the publication database Scopus to analyze the trends of graphene publication activity in Europe, the United States, and Asia over the 2002-2012 time period. Based on Scopus, Small et al. [23] identified the top 25 emerging topics in graphene which are suitable for inspection by decision makers.

However, the existing literature on graphene patenting activities is few in number. Kwon et al. [24] applied specialization scores for graphene patents to achieve more comprehensive navigation of the technological innovation trajectory. Shapira et al. [25] analyzed early corporate entry and activity in graphene technology by using evidence from patent activity across country and application lines. Baglieri et al. [26] compared the patent activities in graphene landscapes between China and Japan, and intended to identify the effect of the organization of the nanotechnology industry. Besides, limited attention has been paid to outlining the development trends of graphene-related patents. The existing patent reviews in the graphene field mainly described a key branch technology, such as graphene nanocomposites, graphene-related smart material, graphene-based electrochemical microsupercapacitors, etc., and explored application trends based on the number of patents [27–29]. In particular, since patents include in-depth information on technology and its market, they have become a significant source for obtaining SCA in the technology market [24]. Therefore, patent analysis regarding graphene technology is required to establish a systematic and comprehensive research framework.

2.2. Development of Multi-level Perspective (MLP)

Due to the huge potential of practical applications, the multi-level perspective (MLP) is regarded as an essential analytical tool in the field of technological innovation since it was first proposed and employed by Geels [30] in 2002. It is also an effective tool for understanding socio-technical transitions, for it provides an integrated analytical framework for drawing on insights from three analytical levels: niches, socio-technical regimes, and the socio-technical landscape, enabling the structure and dynamics of socio-technical systems to be displayed in the framework [31,32]. Niches form the micro-level, the locus where radical innovations emerge. Market niches (e.g., enterprises) and technology niches (e.g., universities and research institutes) are the two main niche-actors [31]. Socio-technical

regimes form the meso-level. The alignment of existing technology, industry, and market results in socio-technical systems [30]. The macro-level is the socio-technical landscape, which forms an exogenous environment that usually changes slowly and influences niches and regime dynamics [33]. It includes environmental problems, political ideologies, and macro-economic trends.

According to the deep research on the MLP, most of the recent studies have applied the MLP for assessing the drivers, barriers, and pathways of transitions in the given industry. Geels [31] introduced the MLP into transport studies; analyzed the interactions between industry, technology, and markets; and illustrated that the MLP can be used for making integrated analyses of the drivers, barriers, and possibilities for transitions. Verbong and Geels [33] proposed a novel approach to transition pathways and explored future transitions in the electricity system. Geels et al. [34] extended the transition pathways typology by reformulating and differentiating the typology through the lens of endogenous enactment and suggesting that transitions may shift between pathways. In addition, studies on the MLP were performed in diverse domains, such as transport, electricity, water, housing, etc. [35] However, a few works, although still limited, have explored this in emerging technology fields, such as low-carbon electricity and renewable energy [34,36]. In the related work, the MLP is considered as a valuable tool for the sustainable transition analysis of emerging technology. Due to the broad system, the MLP thus benefits researchers and practitioners in the emerging technology field for identifying the processes and actors involved in sustainable social change [32]. Furthermore, most of the above-presented studies are qualitative instead of quantitative. Due to the subjective nature of an expert's experience and knowledge, the results may suffer from weak validity and reliability [37]. Therefore, the analytical tools of the MLP need to be improved. We argue that these can be assuaged by the use of patent analysis in the MLP framework.

3. Methodology and Data

The purpose of this study is to identify SCA in the given technology field. The initial research term is based on related literature and technical experts' advice. After setting up a suitable patent retrieval query, we download patent data. In the methodology, building up the patent-based MLP on SCA is the key to the whole research process. From the spatial dimension, the patent-based MLP intends to explore SCA through macro, meso, and micro perspectives. From the temporal dimension, we divide the patent-based MLP into four stages based on the technology life cycle (TLC): emerging, growth, maturity, and saturation. Regarding patent analysis, there are two steps. First, SCA analysis from patent information includes the following basic tasks: recognizing technological development trends, mining technological hotspots and fronts, identifying key competitors, and finding high value patents. Second, patent data is imported into text clustering analysis and visual analysis software. After the patent analysis process, it is essential for this paper to handle and interpret the results of the analysis. Figure 1 indicates the overall process of the proposed method for obtaining SCA (Figure 1).
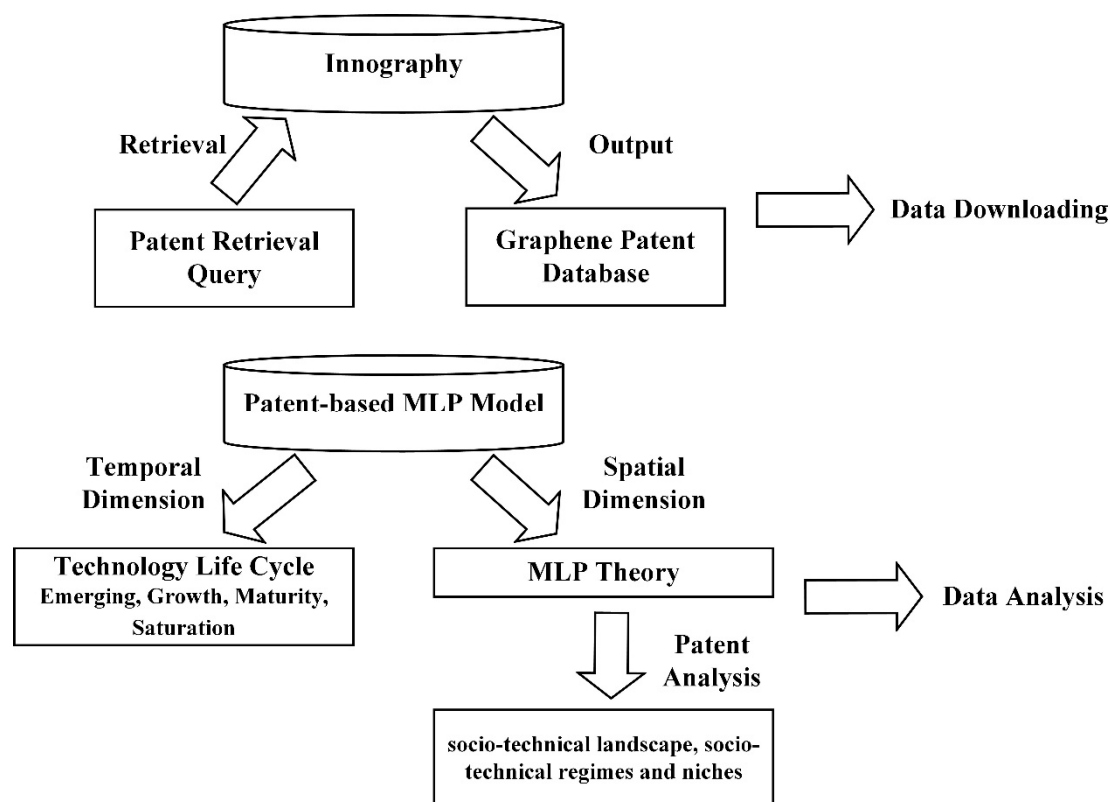
Figure 1. The outline of the research process.

3.1. The Patent-based MLP on Sustainable Competitive Advantage

Sustainable competitive advantage (SCA) is regarded as the ultimate embodiment of an organization's capabilities, resources, and activities, and it is a crucial engine for promoting sustainable economic growth and formulating national technology strategies and policies for the development of sustainable technologies [38]. Over the last decade, some researchers [39,40] have indicated that developing successful technological innovations is essential for obtaining on organization's SCA. Since the knowledge economy era of big data is coming, how to acquire and sustain SCA in a scientific way is not easy. The patent information, which contains enormous and rich technology information, is a key intangible asset and one of the most important indicators that helps organizations or governments to successfully obtain SCA; find new development opportunities; avoid unnecessary investment or potential risks; and support the development of technological innovation, strategy, and policy [41]. Numerous studies have suggested that patents have been considered as a type of resource and value creation for providing a basis for a more-enduring competitive advantage, because they are not only resources of technological innovative subjects, but also capability and the knowledge [42,43]. The number of patents and high quality patents are the two most important patent indicators for assessing SCA [7,44]. The number of patents is regarded as vital temporal information, which can be employed to track the dynamic evolution trends of different technological innovative subjects in a target technology [45]. The patentee with a large number of patents can likely occupy a large market share, collect financial rewards through licensing revenues, and sustain a competitive advantage [46]. High quality patents, which are more difficult for competitors to imitate, can capture large returns from royalties, and help firms be highly valued by the stock market and acquire SCA [47,48]. Other researchers focus on how to formulate proper patent strategies to obtain SCA under the process of technological innovation development [49,50]. However, the studies above focused on recognizing the connection between patent indicators and SCA through statistical analysis, as well as formulating patent strategies of SCA, but few have extended the research on SCA to the patentees from a micro-level perspective and the exogenous environment from a macro-level

perspective, and even fewer have proposed a comprehensive framework for obtaining SCA under the perspective of patent analysis.

In this paper, by introducing patent indicators to the previous MLP model, we attempt to build a new and comprehensive review research framework for the patent-based MLP for identifying SCA in the target technological field. From the spatial perspective, the patent-based MLP intends to explore SCA through macro, meso, and micro perspectives, to create a full understanding. In addition, patent indicators are easy to choose and assess under the meso socio-technical regimes and micro niches of the patent-based MLP. Patent indicators also include all essential factors of SCA. Levels, dimensions, and patent indicators can be matched one by one, and can be supported by relevant literature. In macro socio-technical landscape-level analysis, landscape developments put pressure on the existing regime and bring development opportunities for niches [51]. The meso socio-technical regimes mainly include three dimensions: Industry, technology, and market. Based on patent analysis, a general overview of technology development trends and SCA with regard to the number of patents appeared to be very promising for industrial activities [52]. How to identify the technological field, dig out research hotspots, and seek technology opportunity by using text clustering analysis are of great importance for identifying SCA from technology dimension [27]. As for the market, patent value has a profound influence on market competition. International patent filings and patent citations are regarded as the two most promising indicators to measure patent value [53]. Because an organization's technological innovation capability is positively related to SCA, the competitive position is of fundamental importance to acquire SCA. When investigating micro niches, apart from the top 20 patent assignees, we also need to pay attention to the patent strength of these patent assignees [54]. Considering the data accessibility and previous research presented above, we employ the following patent indicators to explore SCA in the graphene industry: the annual trend of patent activities, patent hotspot, number of international patent filings, number of forward citations, competitive position of top assignees, and top assignees holding a high-strength patent. From the temporal perspective, both the patent-based SCA analysis and the MLP have dynamic characteristics, so we introduce technology life cycle theory into this patent-based MLP framework. The concept of the technology life cycle (TLC) was proposed by Little [55] to measure technological changes. Generally, the S-curve is employed for illustrating technological performance and assessing TLC. Corresponding to product life cycles, we can differentiate emerging, growth, maturity, and saturation as TLC stages [56]. Therefore, we divide the patent analysis into four stages: emerging, growth, maturity, and saturation, and explore the dynamic SCA from micro niches, meso socio-technical regimes, and macro socio-technical landscape levels. This review research framework accords with the level and dimension characteristics of patent-based SCA analysis and the MLP, and has theoretical feasibility. As shown in Figure 2, we propose the new integrated analytical framework of patent-based MLP on SCA.
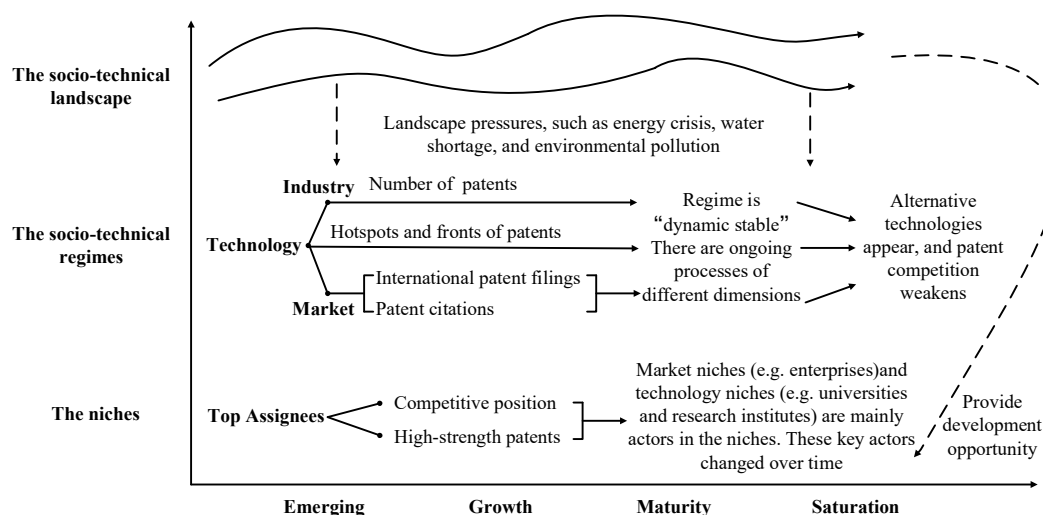
Figure 2. The patent-based multi-level perspective on sustainable competitive advantage.

3.2. Retrieval of Patent Information

Obtaining accurate patent data for analysis is a significant condition for obtaining SCA in this study. In order to set a suitable patent retrieval, we used the professional IP intelligence software INNOGRAPHY, available from https://www.innography.com/ [57]. INNOGRAOHY, first launched in the Austin, Texas of the U.S. in 2007, was acquired by CPA Global, the world's leading specialist in intellectual property software and services. Possessing a well-known advantage of combining unique correlation and visualization technologies to integrate patent data with financial, litigation, market, and business information, INNOGRAPHY enables patent owners, innovators, and decision-makers to quickly gain valuable insights for managing, extending, and exploiting their patent portfolios, as well as the business value of IP investments.

In order to improve the relevancy of our patent research, we looked through related literature and consulted technical experts' advice. The International Union of Pure and Applied Chemistry (IUPAC) defined "graphene" as "a single carbon layer of the graphite structure". Previous studies have used "graphene" as a search term in bibliometric or patent queries [25,26]. We used a broader criterion for the selection of graphene patents. A patent is regarded as valid if the term graphene appears simultaneously in abstracts as well as titles. Since the patents prior to 2004 are sparse, we only retrieve patents filed in the period 2004-2017 for analysis. As a result, 53644 graphene technology patents were obtained for the period from 2004 to 2017 and downloaded from INNOGRAPHY. Data extraction was completed on May 12, 2018. In addition, due to the 18-month lag period of patents, the number of graphene patents in both 2016 and 2017 is incomplete, but it does not affect the analysis of SCA in the field of graphene technology. In order to take full advantage of different patent databases and optimize the objectivity and accuracy of patent analysis, we download graphene patent data from the Derwent Innovation Index (DII) based on the same retrieval strategy and query as that in INNOGRAPHY, available from https://clarivate.com/products/derwent-innovation/ [58], and CitespaceIII, which is a freely available Java application for visualizing and analyzing trends and patterns in scientific literature. The obtained results from DII were then imported into the CitespaceIII. CitespaceIII allows the analysis of patent data and their visualization in many ways, such as mapping, clustering, and citation networks, which will be used in the socio-technical regime to dig out research hotspots and seek technological development opportunity [59].

4. Analysis

4.1. Technology Life Cycle

Ernst [60] introduced four stages of the technology life cycle (TLC), namely: emerging, growth, maturity, and saturation, and developed a map to illustrate the TLC (See Figure 3). The S-curve, which is illustrated in Figure 3, observes technological performance in terms of time. In the emerging stage, the technology is still new to the market. There are new technologies with low patent applications. The characteristic of the growth stage is a pacing technology with an increasing number of patent applications. In the maturity stage, some pacing technologies turn into key technologies. There are high patent applications in this stage. As soon as a technology loses its competitive impact, it becomes a base technology with low patent application. It enters the saturation stage and might be replaced by a new technology [61]. In this paper, we employ the accumulated number of patents and the S-curve to identify the current life cycle stage of technology.
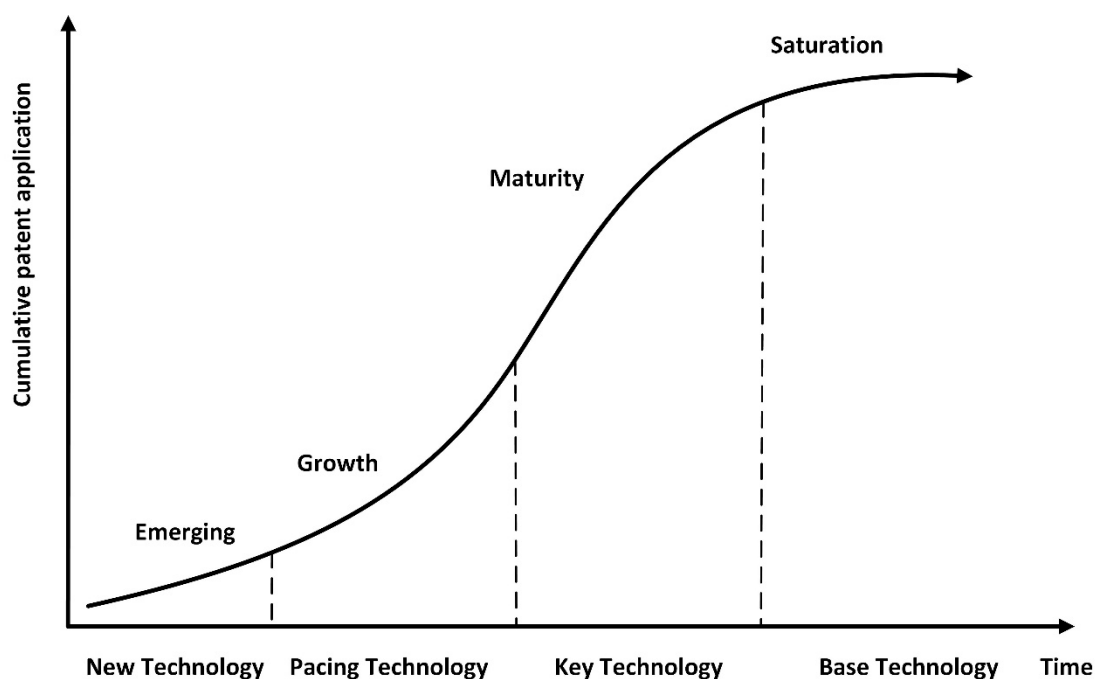

Figure 3. The S-curve concept of the technology life cycle.

As depicted in Figure 4, the TLC of graphene technology can be divided into (1) Emerging stage (from the year of 2004 to 2010): Grapehene was discovered by Prof. Andre Geim and Prof. Kostya Novoselov at The University of Manchester in 2004. Graphene patents increased linearly in the emerging stage, when many countries or regions started graphene scientific research [15]; (2) Growth stage (from the year of 2011 to 2017): In 2010, the Nobel Prize in physics was awarded to University of Manchester researchers Andre Geim and Konstantin Novoselov for their pioneering work on graphene [62]. After that, many countries started to invest funding and formulate related policies to support the development of graphene technology [15]. In addition, a rapid worldwide growth in graphene patenting activity is evident. Graphene patenting took off in about 2011, followed by a remarkable increase in the most recent five years. The graphene-related patents in this period account for 93% of total patents. It is interesting to find that the patents in the most recent three years account for half of all the 53644 patents. In summary, the graphene-related patent is an emerging and increasingly popular technological field.
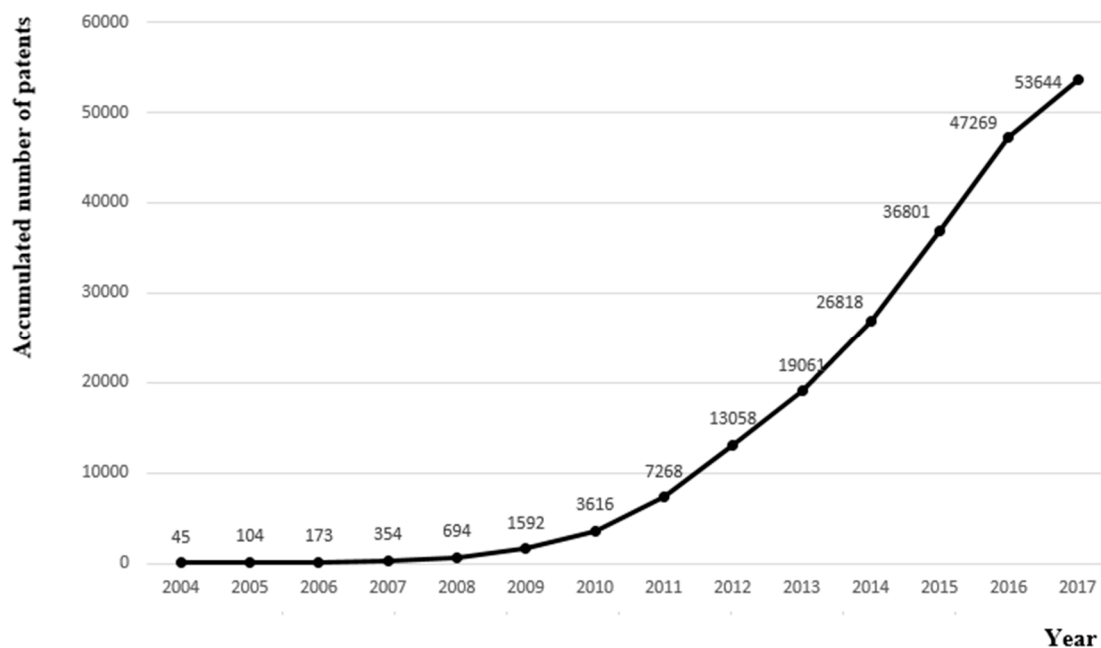
Figure 4. Technology life cycle of graphene technology.

4.2. The Socio-Technical Landscape

There were evident landscape pressures—environmental, economic, and cultural—that in turn, impacted SCA during the innovation process. The graphene technology faces landscape pressures of energy crises, water shortages, and environmental pollution, as follows:

(1) Energy may very well be the most critical challenge facing humanity in terms of electricity and transportation purposes in daily lives. Discussions of energy crisis have led to public concerns and some policy actions at the global level. Due to the growing energy demand and lack of fossil fuel resources, thermoelectric technology, an attractive alternatively renewable energy, can be used to generate electricity via transforming temperature into electricity. With high electrical and thermal conductivity, graphene is regarded as a promising thermoelectric material for electricity generation, which degrades the overall thermoelectric performance [63]. Energy storage, with high power and energy densities, is key to addressing the colossal energy requirements against the backdrop of global warming and the looming energy crisis [64]. Graphene, which is formed from layers of carbon a single atom thick, is of great significance in energy storage, because it has a tremendous surface area for a given amount of material. In the present scenario, graphene is a promising electrode material for energy storage devices, such as supercapacitors, secondary cells, lithium ion batteries, etc.;

(2) A combination of climate change and poor resource management is leading to water shortages. Currently, there are more than one hundred countries face different levels of fresh water shortage. Graphene-oxide membranes have attracted considerable attention as promising candidates for new filtration technologies. According to the new findings from a group of scientists at The University of Manchester that were published in the journal Nature Nanotechnology, a graphene sieve turns seawater into drinking water. The research on graphene-oxide membranes shows exciting potential for providing clean drinking water for millions of people who struggle to access adequate clean water sources [65];

(3) Environmental pollution is accelerating in the twenty-first century. Graphene, as an emerging material for environmental remediation and pollutant removal, possesses outstanding physicochemical properties, and it can be used to reduce the pollutant concentration by adsorption, decompose pollutants to less toxic molecules, and reduce low-valency species [66]. For example, graphene-based adsorbents show high adsorption capacities toward heavy metal ions such as Cu(II), Pb(II), Cd(II), and Co(II), and organic pollutants, especially benzene-containing compounds [67]. With large surface

areas, functionalized surfaces, and active photocatalytic nanoparticles, graphene-based photocatalysts can be used as photoreductants or photodegradants.

4.3. The Socio-Technical Regimes

The socio-technical regimes refer to a series of rules which are abided and implemented by different subjects in the target industry, and involve aspects such as technological innovation, market, industry, and so on. This paper analyzes the socio-technical regimes from three dimensions: industry, technology, and market. The annual trend of patent activities is an important indicator of industry dimension, aiming at the general overview of technological development and competitive advantage of the graphene industry. The technology dimension emphasizes hotspots and fronts that have SCA, while the market dimension attaches great importance to high value patents with a competitive advantage by analyzing the number of international patent filings and number of forward citations.

4.3.1. Industry

A general overview and development trends of graphene technology are illustrated in this section. Due to economies of scales, market competition, labor costs, and first mover advantages, it is worth noting that different countries or regions have different competitive capacities in a given technological field. Table 2 presents evolution trends of the top eight countries or regions leading the graphene race, ranked by the number of patents. Looking at patenting activity at the national level, the U.S., Korea, China, and Japan are the top four countries with a higher SCA in the emerging stage, with more than 700 patents each, while these four countries were also ranked as the top four in the growth stage. In total, the top four possess over 91% of the global inventions in this field. It seems that the Asian region (China 60.7%, Korea 13.6%, Japan 5.9%, and Taiwan 1.8%) has the highest number of graphene-related patents in total. In the EU region, the U.K, Germany, and France play the dominant roles in graphene patenting activity, but they are far behind the Asian actors and the U.S. Regarding the total number of graphene patents, China alone holds 60.7% of the global share, and serves as the leading country in this field.

Table 2. Number of graphene patents per country/region.

Country	Emerging Stage		Growth Stage		Total	
	Number of patents	Percentage	Number of patents	Percentage	Number of patents	Percentage
China	742	20.8%	31,400	63.5%	32,142	60.7%
Korea	848	23.7%	6327	12.8%	7175	13.6%
The U.S.	1019	28.5%	4982	10.1%	6001	11.3%
Japan	480	13.4%	2636	5.3%	3116	5.9%
Taiwan	31	0.9%	897	1.8%	928	1.8%
The U.K	38	1.1%	746	1.5%	784	1.5%
Germany	112	3.1%	423	0.9%	535	1.0%
France	78	2.2%	229	0.5%	307	0.6%

As shown in Figure 5, in the emerging stage, the U.S. and Japan started earlier than other countries or regions in the graphene technology field. After the year 2010, the top three countries from high to low rank are China, Korea, and the U.S. China, with a steadily increasing number of patents, serves as a technology catcher and becomes the largest country for graphene patent applications. The number of Chinese patents increased from a global share of 20.8% in the emerging stage to 63.5% in the growth stage. One reason for this could be due to China's large market and abundant graphite resources, which provides good development opportunities for Chinese actors. The other reason is China's evaluation system, which attaches great importance to patents, as investigated by Tang et al. [68]. Korea, owing a total of 7175 patents, is slightly in front of the U.S. In 2015, the number of patents in Korea experienced explosive growth. This development trend indicates that Korea focuses on graphene technology and

will also be a strong competitor, with a relatively higher SCA in this field. As shown, the U.S., with a higher SCA, has taken the lead in both the emerging and growth stage. One tangible reason for this is that the U.S. entered the market earlier and had the first mover advantages. However, our data indicate that since 2014, the annual number of patents in Japan has not exceeded 500, which gradually weakens Japan's leading position and SCA in this field.
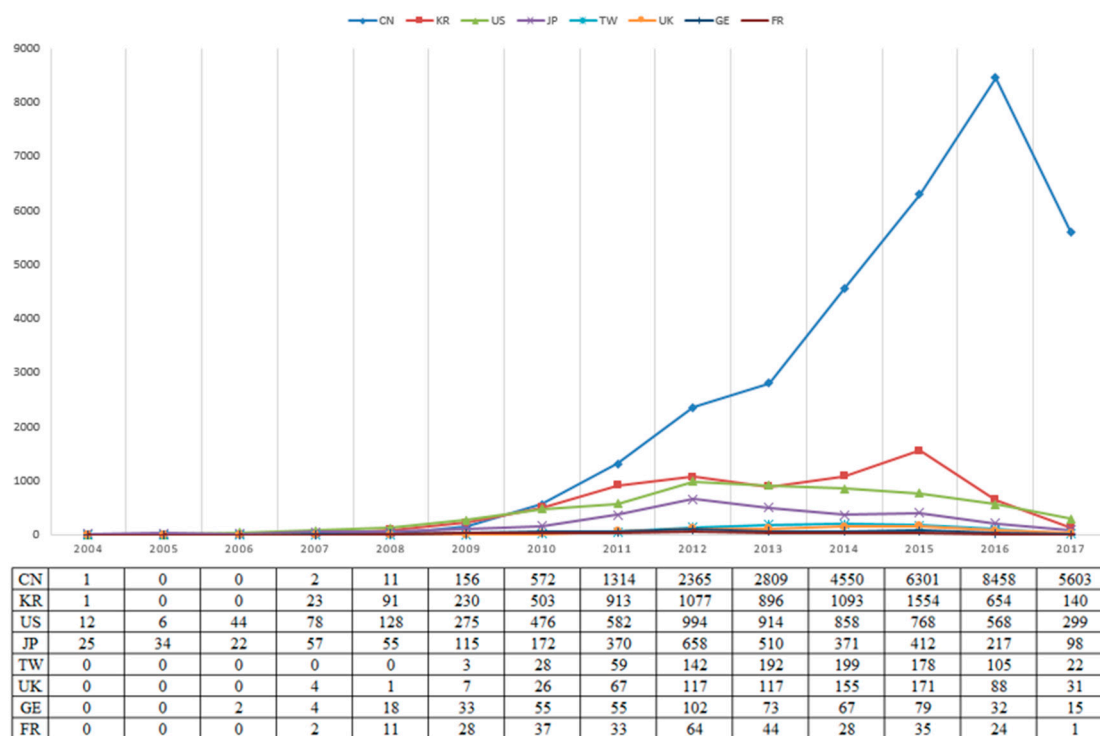

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CN	1	0	0	2	11	156	572	1314	2365	2809	4550	6301	8458	5603
KR	1	0	0	23	91	230	503	913	1077	896	1093	1554	654	140
US	12	6	44	78	128	275	476	582	994	914	858	768	568	299
JP	25	34	22	57	55	115	172	370	658	510	371	412	217	98
TW	0	0	0	0	0	3	28	59	142	192	199	178	105	22
UK	0	0	0	4	1	7	26	67	117	117	155	171	88	31
GE	0	0	2	4	18	33	55	55	102	73	67	79	32	15
FR	0	0	0	2	11	28	37	33	64	44	28	35	24	1

Figure 5. Graphene patents by country/region.

4.3.2. Technology

In order to dig out more useful patent information for research hotspots and technology opportunity that have SCA, we used CiteSpaceIII to make a clustering and co-occurrence analysis in the graphene field through the cross-database retrieval method. The clustering and co-occurrence analysis can complement it by integrating the Manual Codes (MC), which were extracted from patent literature. The MC index the inventive and significant aspects of an invention, plus its commercial applications, and categorize all patents according to this indexing technology classification system. Using the MC can significantly assist researchers and practitioners to identify research hotspots and fronts. If the two MC appear in the same literature, then the two MC have a relationship of co-occurrence. CiteSpaceIII is a freely available Java application for analyzing technological hotspots and fronts, technological competitive trends, and patterns of the specific technological field, and can be used for clustering analysis, network analysis, historical pattern analysis, and so on [69–71]. The patent data were imported into CiteSpaceIII for analyzing the MC and clustering patent texts. The slice length is one year.

In general, each node represents a single MC, and the size of the node represents the frequency. The node with the highest frequency indicates that this node attracts the highest degree of concern, and represents the research hotspot in this field. Through text clustering analysis by CiteSpaceIII, the top three high frequency nodes in the emerging stage are L03-A02B (Non metal conductors—carbon and graphite), A12-W14 (Nanotechnology), and E05-U03 (Carbon nanotubes), which means that the research hotspots focus on fundamental research, such as the raw material, structure, and properties of graphene. In the growth stage, E05-U05C (Nanofilm) ranked first, followed by L03-H05 (Vehicles)

and E11-A01 (Cyclisation—Processes, Apparatus), which shows that the research hotspots pay close attention to technological application and material preparation.

Frequency is an indicator that reflects the hotspot of the technology, while centrality represents the importance and influence power of the technology and illustrates the new research front. The link between different nodes is used to indicate that co-occurrence exists between the MC. The more connections between a node and other nodes, the higher the centrality of the MC. Considering frequency and centrality, the top ten hotspots and fronts that have SCA in the graphene field are shown in Tables 3 and 4.

As can be seen in Table 3, A12-E06A (Electrodes for batteries, accumulators, fuel cells) has the highest centrality and a relatively low frequency in the emerging stage, which indicates that graphene electrodes are of great importance in future development. The hotspots and fronts of graphene patents in the growth stage (See Table 4) illustrate this point. L04-C11C (Semiconductor processing—electrodes), E05-U03 (Carbon nanotubes), L03-A02B (Non metal conductors—carbon and graphite), and A12-W14 (Nanotechnology) have relatively high centrality, as well as high frequency. It is clear that the research on these four fields has been very active and acquires SCA in the emerging stage. Other potential research fronts include A08-R03 (Carbon fillers and reinforcing agents), L03-A02G (Conductive Nanomaterials), E05-U05C (Nanofilm), E31-N04D (Other form of C, inert), and U11-A14 (Nano-structural materials), which are mainly the fundamental properties and nanomaterial of graphene technology.

Table 4 lists the top ten hotspots and fronts that have SCA in the growth stage. Regarding high frequency and high centrality, L03-A02B (Non metal conductors—carbon and graphite) and E05-U05C (Nanofilm) are ahead of other technological fields, suggesting their comparative competitive advantages and crucial roles of technological hotspots in the growth stage. Graphene, as a non-metal nanomaterial, has emerged as a promising candidate to replace conventional transparent conductors due to its low opacity, high carrier mobility, and flexible structure [72]. Graphene films have extraordinary properties, such as transparency, conductivity, and mobility, and have good development prospects in the electronics, photonics, and photoelectric equipment field. For example, graphene films in the supercapacitors are suitable for a wide variety of applications, including hybrid vehicles and personal electronics, such as cell phones, laptops, and mp3 players [73]. L04-C11C (Semiconductor processing–electrodes) and A12-E14 (Electrodes) have a relatively high centrality and low frequency, which indicates that they are closely connected with other technologies and promising for future development. For applications in electrochemical devices, graphene possesses excellent properties, such as a highly tunable surface area, outstanding electrical conductivity, good chemical stability, and excellent mechanical behavior. Graphene constructed carbon paste electrodes, surface film modified electrodes, and micro/nanoelectrodes have been developed to determine various species, such as glucose, DA, AA, nicotinamide adenine dinucleotide, hydrogen peroxide, and DNA [74]. These graphene-based electrodes are promising for applications in supercapacitors, batteries, accumulators, fuel cells, and so on. Other research hotspots and fronts include E11-A01 (Cyclisation—Processes, Apparatus), L03-H05 (Vehicles), A10-E05B (Chemical modification by carbonization), E11-F03 (Alkylation, arylation, acylation of C atoms, condensation; other carbon chain extension reformation), X16-B01F1 (Lithium-based), and L03-E01B5B (Lithium electrodes), which mainly related to the application of graphene technology in transportation, electronics, chemistry, etc.

One interesting observation emerges. The structure of graphene patents remains rather steady: the three categories of E05-U05C (Nanofilm), L04-C11C (Semiconductor processing—electrodes), and L03-A02B (Non metal conductors—carbon and graphite) consistently dominate in the emerging stage and growth stage.

Table 3. Hotspots and fronts of graphene patents in the emerging stage.

Derwent Manual Code	Technological Field	Centrality	Frequency
A12-E06A	Electrodes for batteries, accumulators, fuel cells	0.28	26
A08-R03	Carbon fillers and reinforcing agents	0.22	27
L03-A02G	Conductive Nanomaterials	0.15	56
E05-U05C	Nanofilm	0.15	41
E31-N04D	Other form of C, inert	0.14	69
U11-A14	Nano-structural materials	0.14	47
L04-C11C	Semiconductor processing—electrodes	0.13	86
E05-U03	Carbon nanotubes	0.13	84
L03-A02B	Non metal conductors—carbon and graphite	0.10	122
A12-W14	Nanotechnology	0.10	100

Table 4. Hotspots and fronts of graphene patents in the growth stage.

Derwent Manual Code	Technological Field	Centrality	Frequency
L03-A02B	Non metal conductors—carbon and graphite	0.29	2105
E05-U05C	Nanofilm	0.23	4298
L04-C11C	Semiconductor processing—electrodes	0.08	537
E11-A01	Cyclisation—Processes, Apparatus	0.06	2114
A12-E14	Electrodes	0.06	882
L03-H05	Vehicles	0.05	2931
A10-E05B	Chemical modification by carbonization	0.05	1219
E11-F03	Alkylation, arylation, acylation of C atoms, condensation; other carbon chain extension reformation	0.04	1643
X16-B01F1	Lithium-based	0.03	1784
L03-E01B5B	Lithium electrodes	0.03	1730

4.3.3. Market

Patent value is of fundamental importance to market competition, as well as SCA. A patent is endowed with "business value" or "private value" if it could be used (for new products, processes or licensed) or strategically possessed (for blocking other firms' technologies) [75]. Patent value can be measured through the patent statistics approach. International patent filings and patent citations are regarded as the two most promising indicators of the patent statistics approach [53].

(1) Number of International Patent Filings

As an indicator seeking protection in a geographical scope, the number of international patent filings represents the market value of patent rights. Generally, the more a patent is filed in other countries or regions, the higher its value and SCA, because the number of international patent filings reflects the efforts and cost incurred by patentees to protect their rights within a broader geography.

The number of graphene patents filed by domestic and foreign countries or regions is shown in Table 5. Regarding the rate of total foreign patent filing, the top five countries with SCA from high to low rank are Germany (74.58%), the U.K (57.78%), France (53.75%), Japan (51.57%), and the U.S. (49.31%). From the emerging stage to growth stage, the foreign patent filing rate of Korea, the U.S., Japan, the U.K, and France increased, while the rate of Germany and Taiwan slightly declined. Although the total number of graphene patents in Germany, the U.K, and France is a lot less than China, Korea, the U.S., and Japan, these three countries in the European region attach great importance to the overseas patent layout, especially in the U.S., WIPO, and EPO. Due to the advantage of entering the graphene industry earlier, the graphene technologies of the U.S. and Japan are relatively mature. Thus, the foreign patent filing rates and competitive advantage of the U.S. and Japan are higher than other countries or regions. It is interesting to note that China, with the largest total number of graphene patents, has the lowest rate of foreign patent filing. From the emerging stage to growth stage, the rate of foreign patent filing in China sharply decreased from 16.31% to 4.13%. China had the

largest numbers of graphene patents filed by applicants from their own countries, which indicates the "home advantage" effect [76]. So far, China has emphasized domestic markets, and has not paid enough attention to opening up the global market. This lack of overseas patent layout will lead to patent infringement risks and a loss of SCA when Chinese actors participate in the competition of global graphene market in the future.

The U.S. is the most active foreign patent filing country in the graphene technology field, followed by WIPO and China, which indicates the main competition markets around the world. Actors from the U.S., China, Korea, Japan, and the U.K pay close attention to the patent layout at WIPO, while actors from the U.S., Japan, Korea, and Taiwan place an emphasis on the patent layout in China.

Table 5. Number of graphene patents filed by domestic and foreign country/region.

Foreign Patent Filing Country/Region	Domestic Patent Filing Country/Region							
	CN	KR	US	JP	TW	UK	GE	FR
CN	30726	245	505	257	82	53	33	10
KR	43	5092	263	152	9	26	34	18
US	448	1109	3042	571	319	116	143	52
JP	149	173	322	1509	13	41	25	23
TW	152	29	120	147	485	8	14	2
UK	93	143	359	126	12	331	110	50
GE	93	143	319	120	0	123	136	52
FR	86	139	317	0	6	118	110	142
WIPO	496	382	885	273	7	141	91	50
EPO	90	141	323	124	5	118	114	54
Foreign patent filing rate in emerging stage (%)	16.31	27.36	48.38	42.08	48.39	55.36	75.90	50.00
Foreign patent filing rate in growth stage (%)	4.13	41.35	49.50	53.30	47.71	57.91	74.23	55.02
Total foreign patent filing rate (%)	4.41	29.03	49.31	51.57	47.74	57.78	74.58	53.75

(2) Number of Patent Citations

A citation is a reference to a previous work (prior art) that is considered relevant to a current patent application. The citations include two different types: forward citations and backward citations. Backward citations are patents that are cited by a specific patent and forward citations are patents that cite a specific patent. Forward citations, namely the citations that a patent receives from subsequent patents, are regarded as a commonly used proxy of patent value. Many studies have shown that the number of forward citations is significantly and positively correlated with the patent value. In general, a patent with more forward citations is more likely to be a basic patent in a given technological field and with a relatively higher SCA [77]. Knowing the economic value and importance of patents helps study the positive relationship between the number of forward citations and firm performance. Chen and Chang [78] verified that the value of citations is positively related to market value. Analyzing forward citations can identify certain competitors that obtain SCA.

Table 6 presents the number of forward citations of the top 20 graphene patents. It can be seen that most of the patents are in the emerging stage, and only two patents are in the growth stage. The number of the U.S.'s forward citation patents on graphene has outstripped that of other countries, such as China, Korea, and Japan. Among the top 20 high-cited graphene patents, twelve belong to the U.S., seven belong to Korea, and one belongs to China, which indicates that the U.S. and Korea have higher SCA in high-cited patents. There are twelve from research enterprises, seven from universities and research institutes, and one from an individual. It shows that enterprise is the main technology strength in the graphene industry. As can be seen from Table 6, the top three patents regarding forward citations are US20070284557 A1 (221), US20090117467 A1 (208), and US20100021708 A1 (185), respectively. US20070284557 A1 filed by Samsung Electronics Co, Ltd. is the patent that has the largest number of forward citations, in which a transparent and conductive film comprising at least one network of graphene flakes is described herein. It was cited since 2007. In addition, Samsung Electronics Co, Ltd has seven high-cited graphene patents, which means that its patents have high value and this enterprise is a key competitor with SCA in the graphene industry. CN103943925 B filed

by Peking University is the only patent among all the top 20 high-cited graphene patents that was filed in China. It was cited since October, 2015. The invention discloses a full-carbon coaxial line and a manufacturing method of the full-carbon coaxial line, and belongs to the technical field of integrated circuits. Graphene serves as a monatomic layer thickness.

Table 6. Number of forward citations of top 20 graphene patents.

Patent Number	Assignee	Number of Forward Citations	Country	Stage
US20070284557 A1	Samsung Electronics Co, Ltd	221	Korea	Emerging stage
US20090117467 A1	Samsung Electronics Co, Ltd	208	Korea	Emerging stage
US20100021708 A1	Massachusetts Institute of Technology	185	the U.S.	Emerging stage
US20100143798 A1	Samsung Electronics Co, Ltd	179	Korea	Emerging stage
US20090020764 A1	Globalfoundries Inc.	177	the U.S.	Emerging stage
US20100176337 A1	Samsung Electronics Co, Ltd	172	Korea	Emerging stage
US20070212538 A1	Oned Material LLC	170	the U.S.	Emerging stage
US20070053168 A1	General Electronics Company	157	the U.S.	Emerging stage
US7623340 B1	Samsung Electronics Co, Ltd	152	Korea	Emerging stage
US20090110627 A1	Samsung Electronics Co, Ltd	139	Korea	Emerging stage
US20120141799 A1	Kub Francis	135	the U.S.	Growth stage
US20080020193 A1	Nanotek Instruments, Inc	132	the U.S.	Emerging stage
US20070187694 A1	Provenance Asset Group LLC	130	the U.S.	Emerging stage
US20100327847 A1	President and Fellows of Harvard College	122	the U.S.	Emerging stage
US20100105834 A1	William Marsh Rice University	118	the U.S.	Emerging stage
CN103943925 B	Peking University	113	China	Growth stage
US20090155561 A1	Samsung Electronics Co, Ltd	111	Korea	Emerging stage
US20090140801 A1	Columbia University	111	the U.S.	Emerging stage
US20100028681 A1	The Leland Stanford Junior University	110	the U.S.	Emerging stage
US20100028559 A1	Portland State University	109	the U.S.	Emerging stage

4.4. The Niches

The niches mainly include market niches (e.g., enterprises) and technology niches (e.g., universities and research institutes). This paper analyzes the top assignees from the graphene industry by using two indicators: competitive position and high-strength patent, which helps to identify key competitors with SCA in this technological field.

4.4.1. Competitive Position of Top Assignees

INNOGRAPHY's patent map is an excellent way to create useful, competitive landscapes that give an accurate view of patent ownership. By integrating a technological (horizontal) axis and a resources (vertical) axis into the plane coordinate system, the map enhances the ability to identify key competitors with SCA, and expand views of the market landscape. Patents, classifications, and citations are the three key factors in the technological axis, while the three key factors in the resources axis are revenue, litigation, and locations. The competitive positions of the top patentees in the emerging stage and growth stage are shown in Figures 6 and 7, respectively.

As can be seen in Figure 6, there are fourteen patentees from enterprises and six patentees from universities and research institutes in the emerging stage. Among these top 20 patentees, we can see that the U.S. (7 patentees), Korea (4 patentees), Japan (3 patentees), and China (3 patentees) are major competitors in the graphene industry. The patentees from the U.S. and Japan are mainly enterprises, such as Nanotek Instruments Inc, International Business Machines Corp, and Fujitsu Limited, while the patentees from Korea and China are closely related to universities or research institutes, such as Korea Advanced Institute of Science and Technology, Chinese Academic of Sciences, and Tsinghua University. Regarding the number of patents, the top three patentees are Samsung Electronics Co., Ltd (256), Ocean King Lighting Science & Technology Co., Ltd (120), and Nanotek Instruments Inc (74). Samsung Electronics Co., Ltd, a multinational Korea company holding 256 patents, is the only competitor located in the area of the upper right quadrant. Due to the first mover advantage in entering the graphene market in 2006, and its innovative ability in the preparation of graphene,

Samsung Electronics Co., Ltd has SCA over patent activities, as well as resources. Therefore, it is a powerful leader in the competitive market at the emerging stage. Nanotek Instruments Inc is a relatively key competitor located in the lower right quadrant, suggesting its competitive advantage in patent actives. Most of the patentees are located in the lower left quadrant, such as Ocean King Lighting Science & Technology Co., Ltd, International Business Machines Corp, Koch Industries, and so on. Lacking both technical strength and resources, these patentees are followers in the competitive market. There is no patentee located in the upper left quadrant.
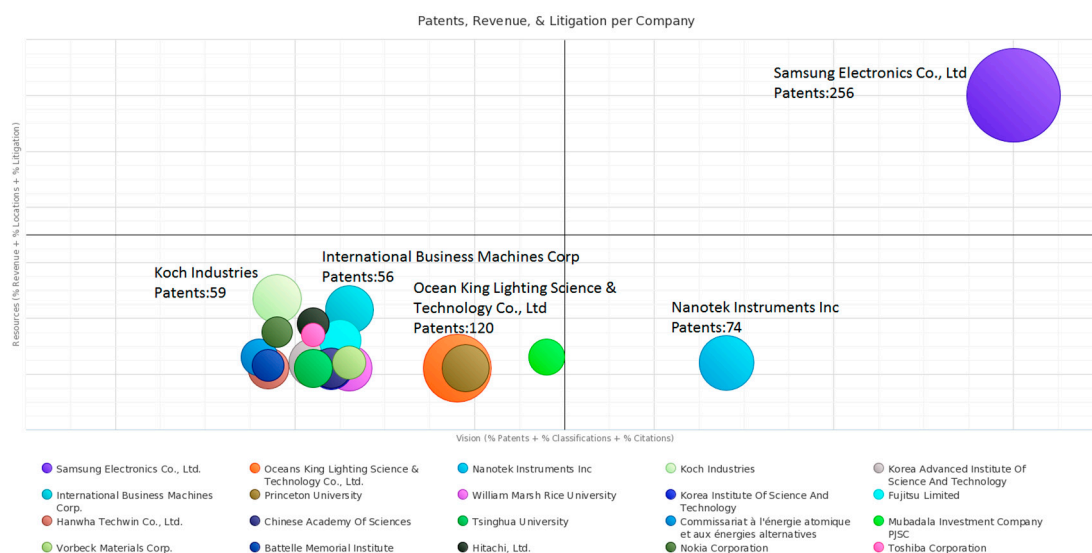
Figure 6. Competitive position of top patentees in the emerging stage.

Figure 7 depicts the competitive position of the top 20 patentees in the field of graphene in the growth stage. Regarding the geographical composition, China (13 patentees) overtakes Korea (3 patentees), the U.S. (2 patentees), and Japan (2 patentees), and takes the lion's share, suggesting its leading position in the graphene industry. However, enterprises from Korea, the U.S., and Japan, including Samsung Electronics Co., Ltd, International Business Machines Corp, and Semiconductor Energy Laboratory Co Ltd, are key competitors with a relatively high technical strength and resources in the growth stage. Samsung Electronics Co., Ltd, a giant conglomerate with a high innovative ability in technological applications such as electronics, energy, materials, and optoelectronics, and intensively R&D investment, is also the only patentee located in the upper right quadrant, which indicates that it has greater comprehensive SCA and is the most important competitor in the graphene industry [79]. International Business Machines Corp, holding 385 patents, is located close to the area of the upper right quadrant. This shows that International Business Machines Corp has s relatively high SCA in technical strength and resources, and would be a key competitor in the future competitive market. However, the graphene patents filed in China that were granted to business firms are lower than the above countries. Among the thirteen patentees in China, there are eleven universities and research institutes, and only two enterprises. Our data show that the key actors of Chinese graphene applicants are the Chinese Academy of Sciences and Chinese elite universities, such as Zhejiang University and Tsinghua University. These three patentees are located in the lower right quadrant, which suggests that they have a competitive advantage in patent actives and a loss in resources. In addition, two Chinese enterprises are also located in the lower right quadrant. Although Ocean King Lighting Science & Technology Co., Ltd holds a relatively large amount of graphene-related patents, its resources' strength remained stalled from the emerging stage to growth stage. This indicates that there are still innovative ability gaps between Chinese enterprises and those from Korea, the U.S., and Japan, and disadvantages in technological industrialization for Chinese enterprises. There is no patentee located in the upper left quadrant.
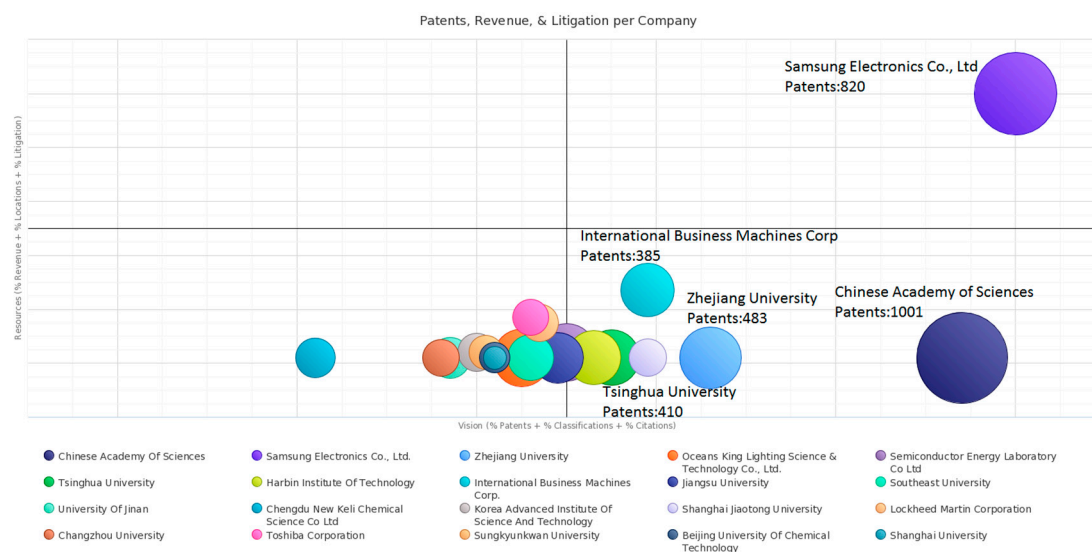
Figure 7. Competitive position of top patentees in the growth stage.

4.4.2. Top Assignees Holding High-Strength Patent

Filed to USPTO on August 6, 2013, PATENTSTRENGTH® is a trademark and brand of INNOGRAPHY. PATENTSTRENGTH®, a new original patent evaluation indicator of INNOGRAPHY, is the latest research from University of California, Berkeley, Stanford University, The University of Texas at Austin, and George Mason University. There are more than 10 key indicators in PATENTSTRENGTH®, including forward citations, backward citations, claim numbers, family numbers, patent age, the revenue from patent licensing, patent litigation, etc. INNOGRAPHY's PatentStrength® focuses detailed analysis on the strongest and most valuable patents, and enables users to identify key assignees holding these high strength patents and obtaining SCA. INNOGRAPHY developed a scale for patent strength from the 0-100th percentile; provided that the patent is considered as a core patent if its patent strength is more than the 80th percentile, an important patent if its patent strength is from the 30-80th percentile, and a general patent if its patent strength is from the 0-30th percentile.

In this paper, we set the patent strength from the 30 to 100th percentile, and we can get 2097 and 10342 high-strength patents related to graphene technology in the emerging stage and the growth stage, respectively. (See Tables 7 and 8). As shown in Table 7, so far as the number of high-strength patents being held is concerned, Samsung Electronics Co., Ltd outstrips other assignees, with 198 high-strength patents and a high SCA, followed successively by Nanotek Instruments Inc (74), Princeton University (44), Oceans King Lighting Science & Technology Co., Ltd (44), and Koch Industries (41), which indicates their SCA in the emerging stage. According to the top 10 assignees' country origin, there are six assignees from the U.S., accounting for 33.8% of the total high-strength patent. Korea has two assignees, with 29.1%, ranked in second place. Table 8 displays the distribution of patent strength for graphene patents in the top 10 assignees in the growth stage. As is shown, Samsung Electronics Co., Ltd, with 412 high-strength patents, still overtakes other assignees, suggesting its leading position and SCA in the graphene competitive marketplace. The Chinese Academy of Sciences and International Business Machines Corp follow with 247 and 179 patents, respectively. As for the country origin, there are four assignees from China, four assignees from the U.S., one assignee from Korea, and one assignee from Japan. In total, 70% of the top 10 assignees are from enterprises, which indicates that most of the assignees attach importance to the marketization and industrialization of patent technology. These enterprises include Samsung Electronics Co., Ltd, International Business Machines Corp, Semiconductor Energy Laboratory Co Ltd, Nanotek Instruments Inc, etc. It can be seen from Tables 7 and 8 that Samsung Electronics Co., Ltd, Nanotek Instruments Inc, Oceans King Lighting Science & Technology Co., Ltd, and International Business Machines Corp are major assignees, with a high SCA in both the emerging and growth stages, accounting for 44.9% and 33.2% of total high-strength

patent, respectively. In addition, Chinese assignees increased from the emerging stage to the growth stage. However, compared to assignees from the U.S., Korea, and Japan, most of the Chinese assignees are from universities and research institutes, indicating the lack of Industry-University-Research Collaboration, which may lead to the loss of SCA. The only Chinese assignee from an enterprise is Oceans King Lighting Science & Technology Co., Ltd, a major supplier of lighting to more than 10 industries, including transportation, power generation, mining, oil and gas, petrochemical, etc.

Table 7. Top 10 assignees holding high-strength patent in the emerging stage.

Assignee	Country Origin	Number of Patent	Percentage
Samsung Electronics Co., Ltd	Korea	198	25.3%
Nanotek Instruments Inc	the U.S.	74	9.5%
Princeton University	the U.S.	44	5.6%
Oceans King Lighting Science & Technology Co., Ltd	China	44	5.6%
Koch Industries	the U.S.	41	5.2%
William Marsh Rice University	the U.S.	41	5.2%
International Business Machines Corp	the U.S.	35	4.5%
Mubadala Investment Company PJSC	United Arab Emirates	33	4.2%
Vorbeck Materials Corp.	the U.S.	30	3.8%
Korea Advanced Institute Of Science And Technology	Korea	30	3.8%

Table 8. Top 10 assignees holding high-strength patent in the growth stage.

Assignee	Country Origin	Number of Patent	Percentage
Samsung Electronics Co., Ltd	Korea	412	16.3%
Chinese Academy of Sciences	China	247	9.8%
International Business Machines Corp	the U.S.	179	7.1%
Semiconductor Energy Laboratory Co Ltd	Japan	138	5.5%
Tsinghua University	China	130	5.1%
Nanotek Instruments Inc	the U.S.	125	4.9%
Oceans King Lighting Science & Technology Co., Ltd	China	123	4.9%
Zhejiang University	China	121	4.8%
Intellectual Ventures Management, LLC	the U.S.	120	4.8%
Lockheed Martin Corperation	the U.S.	112	4.4%

5. Conclusions and Discussions

This study presents a systematic review on sustainable competitive advantage (SCA) in the graphene field based on a new patent-based multi-level perspective (MLP) model that integrates patent analysis with technology life cycle (TLC). The increasing number of patents over the year indicates that graphene-related patents have attracted the fast growing attention of both researchers and practitioners. Although it is evolving into a popular research field, a comprehensive patent analysis to scientifically reveal SCA has not been conducted. In recent years, some researchers came up with the idea that the number of patents is one of the indicators of SCA, while others paid great attention to the relationship between high value patents and SCA. Scherer and Harhoff proposed that the top 10% of the most valuable patents captured from 48% to 93 % of the total sample value of all patents through statistical analysis [77]. This means that we should regard both the number of patents and high value patents as the indicators of describing SCA in the given technology field. Taking into consideration the noise and biases in patent information, we select proper patent indicators, including the annual trend of patent activities, patent hotspot, number of international patent filings, number of forward citations, competitive position of top assignees, and high-strength patents, to assess SCA and the dynamic technological competitive postures from the perspectives of the macro landscape, meso socio-technical regimes, and micro niches. The graphene technology is selected as a case study, through which the proposed patent-based MLP has been proven to be valid and robust. The initial effort has contributed to the target technology marketplace by obtaining SCA from patent information and attempting to catch up the technological competition ability, not only acknowledging current technological competitive development in the given technological field, but also enlightening future directions.

5.1. Main Findings and Contributions

Several interesting findings from this paper are worth noting. In terms of the annual trend of patent activities, our study demonstrates that globally, graphene innovations are concentrated in Asia and North America, such as China, Korea, the U.S., and Japan. As a first mover, the U.S. has held the maximum patent applications in the emerging stage. With the increasing patent activities and technology advancements of graphene in recent years, China has an obvious competitive advantage over other countries in patent applications in the growth stage. However, when it comes to international patent filings, the European region, the U.S., and Japan has outstripped China and Korea in both the emerging and growth stage. It is interesting to find that only the foreign patent filing rate of China declined rapidly from the emerging stage to the growth stage, which indicates that Chinese actors only place an emphasis on the domestic market and lack the awareness of overseas patent layout. Furthermore, our data on the top 20 high-cited graphene patents reveals that most of the high value patents belong to the U.S. and Korea. This suggests that they have a stronger SCA of high value patents than China in the field of graphene technology. The SCA of the U.S. and Korea in the graphene technology field is also reflected by enterprises with stronger innovative capabilities. These powerful leaders include Samsung Electronics Co., Ltd, International Business Machines Corp, Nanotek Instruments Inc, etc. Compared with assignees from the U.S., Korea, and Japan, most of the Chinese assignees are from universities and research institutes, such as the Chinese Academy of Sciences, Tsinghua University, Zhejiang University, etc. Generally, the non-commercial motivation to get involved in patent activities for inventors of university-owned or research institute-owned patents is mostly concerned with intangible rewards, as well as the desire to get more funds for research, but not for practice and commercialization [75]. As for hotspots and fronts in the graphene fields, the three categories of E05-U05C (Nanofilm), L04-C11C (Semiconductor processing–electrodes), and L03-A02B (Non metal conductors-carbon and graphite) consistently dominate in the emerging stage and growth stage. The findings indicated that nanotechnology, nanofilm, transport tools, fillers and reinforcing agents, and electrodes, which were largely in the fields of electrochemistry, were the hotspots in research fields recently. In summary, regarding SCA, the U.S., having patents with a high foreign patent filing rate, high forward citations, and assignees with stronger innovative capabilities in both the competitive position and high-strength patents, is still the most powerful leader in the graphene industry. Due to the competition position, and high-cited and high strength patents, Korea also obtains SCA and will be a promising competitor in the global graphene industry. Although China is catching-up very rapidly in the total number of graphene patents, the apparent innovation gaps in the foreign patent filing rate, high value patents, and Industry-University-Research Collaboration will obviously hamper the catch-up efforts of China's graphene industry. Therefore, there is still a long way to go for the Chinese government to facilitate the development and industrialization of graphene technology, and maintain its SCA in the graphene technology.

This study makes an important contribution toward obtaining SCA in a target technology field by introducing a patent-based MLP model that has not appeared in existing review research, as well as an SCA methodology. The contribution of this paper mainly has the following aspects. First, based on the proposed patent-based MLP, it provides a new and comprehensive analytical framework for review research, as well as SCA analysis, and extends its research perspectives, namely the macro socio-technical landscape, meso socio-technical regimes, and micro niches. Second, it introduces patent indicators to the previous MLP model, and further develops the concept of patent-based MLP, which provides a new theoretical perspective for the study of technological innovation in the previous MLP model. Due to the simple process of collecting patent data, this framework exerts a good effect in obtaining SCA in the target technology field. Moreover, the proposed patent-based MLP can be applied not only to graphene, but to various other areas of emerging technology. Third, this study employs the technology life cycle theory to build the patent-based MLP, which divides the patent analysis into four stages: emerging, growth, maturity, and saturation, and explores the dynamic SCA in the given

technology field. Compared with the previous research on the MLP, it further develops the concept of the MLP from the temporal dimension.

5.2. Future Research Directions

From the existing literature review and technological competitive trends of graphene-related patents, several future research directions can be proposed for further study. First, as discussed above, many studies considering patent information have widely recognized it as the key to SCA, but fewer studies have explored expressive indicators of competitive advantage by using descriptive data originating from patent analysis. Taking into consideration the noise and biases in these descriptive data, it is necessary to carry out a questionnaire survey in leading enterprises, universities, or research institutes to acquire more practical and valuable data as a supplement. Future studies could put more effort into exploring to what extent these descriptive data affect SCA by applying statistical analysis, and apply it to other emerging technologies, in addition to graphene technology. Second, in terms of research methodologies, it is suggested that the methods used in this paper should be further improved. Besides the patent analysis, other approaches, such as patent roadmapping, main path analysis, and social network analysis, would also be effective to achieve the research purpose. In particular, patent roadmapping and main path analysis attempt to illustrate and visualize dynamic technological competition, and contribute to hotspots and fronts of a target technological field. Social network analysis has been proven to be an efficient method to identify central researchers and institutions over time. Future studies could put more effort into constructing a collaboration network of patentees, which can help uncover this issue more comprehensively. Third, while most articles we reviewed only focus on the meso- or micro-level of patent-based SCA, more studies are needed in the future to further expand the dimensions of the proposed patent-based MLP on SCA, so that more comprehensive perspectives can be provided for identifying SCA in the specific technology field. In future studies, we plan to add more dimensions, such as the policy perspective, in the socio-technical regimes.

5.3. Limitations

Despite its contributions, several limitations of our work need to be considered. First, with the fast development of a given technological field, the research results will change dynamically due to the increasing number of patents. Future studies may continue to obtain deeper insights into their dynamic evolution in the maturity stage and saturation stage. Second, the dimensions and levels considered in the proposed patent-based MLP need to be further expanded, so that it can provide more perspectives for obtaining SCA through patent analysis.

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